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RTPS Telemetry - Simulator Link
at
Naval Air Warfare Center

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ABSTRACT

Over the last 3 years the Naval Air Warfare Center Aircraft Division (NAWCAD), Patuxent River, MD, has been in the process of developing a link between its secure Manned Flight Simulator (MFS) and Real Time Processing System (RTPS) facilities. The MFS hosts a wide variety of high fidelity fixed and rotary wing aircraft simulation models. The RTPS is used as a telemetry ground station for conduct of Navy flight testing at Patuxent River MD. The ability to integrate simulation with flight testing in a real time environment provides new potential for increased flight safety, enhanced engineering training, optimized flight test planning, real time simulation fidelity assessments, improved engineering analysis and other applications for enhanced flight testing, data analysis and data processing. A prototype system has been successfully designed and operated at NAWCAD in support of an F/A-18C flight test project which required simultaneous merging and display of real time and simulation data to reduce the risk of departure from controlled flight. As currently designed the link (encryption and decryption gear in the loop) can be operated in three modes: (1) Simulation sending data to RTPS (e.g. pilot-engineer pre-first flight preparation/training scenario, (2) simulation is driven by real aircraft control surface inputs and response is compared with that of the real aircraft for simulation fidelity assessments and (3) simulation "rides along" with the real aircraft and data are extracted from the simulation which are otherwise unavailable from the aircraft (e.g. flight control law interconnect signals, control law feedback signals, aerodynamic data, propulsion model data, avionics model data, other model data etc.).

This paper discusses, design and implementation aspects of the RTPS-Simulator link, and includes a description of how the link was used to support a real time flight test program by providing critical safety of flight data. Other potential uses for the link will also be highlighted.

KEY WORDS

Aircraft Simulation, Simulation Link, Telemetry Simulation Link, Real Time Processing System, Flight Testing.

INTRODUCTION

In 1973 the Naval Air Warfare Center Aircraft Division, Flight Test & Engineering Group (FTEG), formerly the Naval Air Test Center, established the Real Time Processing System (RTPS). RTPS has been used extensively to support numerous aircraft test programs at NAWCAD. At RTPS flight defined critical parameters are displayed in real time to project engineers for safety of flight, project monitoring and preliminary analysis. The data are displayed in Engineering Unit (EU) format onto CRT's, alphanumeric displays, and strip-chart recorders. With all these display devices and the ability to process high-sample-rate data, multiple data flights are flown daily. The EU data are recorded onto 9-track tape for post-flight analysis via high-speed remotely located processors. Data and plots can be processed and formatted more quickly, a wider variety of data and plot types can be formulated, and the data can be placed onto

mainframe disk packs for future retrieval, time history and trend analysis. RTPS system architecture is illustrated in Figure 1.

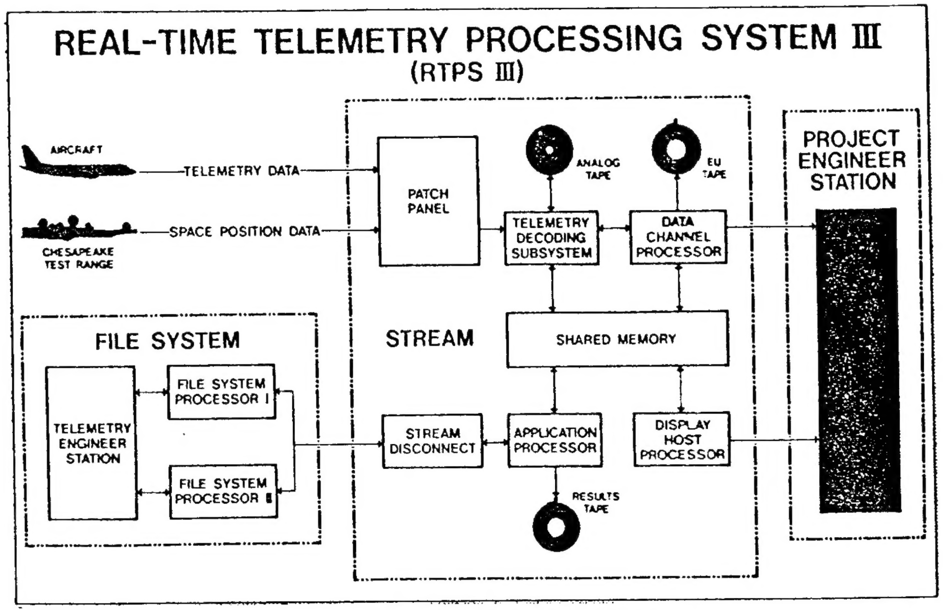

Figure 1. RTPS Architecture

In Oct. 1984 the Manned Flight Simulator Facility was established. Since then high fidelity simulations have been implemented and used increasingly to support test and evaluation at NAWCAD.The MFS facility includes several simulation stations that support high fidelity cockpits, aerodynamic and propulsion models, and avionics simulations. The facility includes a 6 Degree of Freedom motion capable station, a fixed base 360 deg field of view 40 ft dome simulation station, two engineering development stations, and a dedicated station for the use of helmet-mounted displays. The distributed Interactive Simulation (DIS) protocol enables multiple simulation stations, covering the spectrum of air-to-air, air-to-ground, combat formation, and training scenarios, to interact with one another. Via DIS, MFS can interact with simulation facilities across the world to further test and evaluate Navy weapon systems. MFS architecture is illustrated in Figure 2.

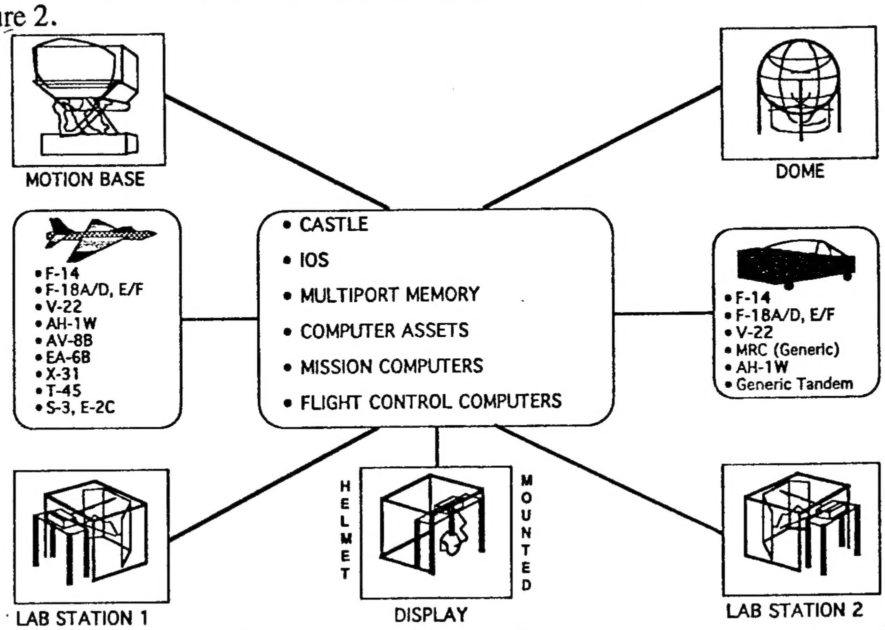

Figure 2. MFS Architecture

While high fidelity simulations have numerous uses, a very important and frequent use at NAWCAD has been to support flight testing, particularly for reducing risk before flight. Typically, pre-test flight profiles are flown at MFS in preparation for actual flight tests. While the concept of merging simulation with flight testing is not new (e.g., X-29 real time calculation of phase and gain margin during flight envelope expansion), the use of real time simulation to support flight testing has not been extensively applied. The idea of combining simulation and real time data in a new way found support through NAWCAD in-house advanced technology initiatives. With the maturation of both the RTPS and MFS facilities at NAWCAD and recent incorporation of encryption decryption capabilities at both facilities over a T1 link the ability to link these facilities became a reality. Until recently it was not possible to link these facilities because the MFS is a secure facility.

LINK DESCRIPTION

Simulation (MFS) Link Configuration

The MFS telemetry/simulator link configuration is illustrated in Figure 3.

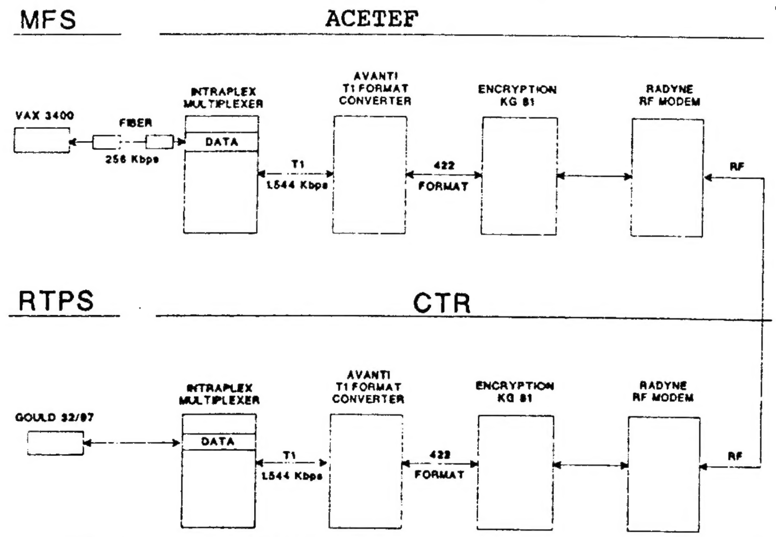

Figure 3. MFS/RTPS Link Configuration

Communications are accomplished by use of a bi-directional 256,000 bits/sec rate Synchronous Data Link Communications (SDLC) interface card. The MFS/RTPS link is interfaced to the MFS through the Air Combat Environment Test and Evaluation Facility (ACETEF) Operations Control Center (OCC). The OCC is the interface for all ACETEF Laboratories of which MFS is one part. The OCC contains KG84 Encryption/Decryption equipment, a time division multiplexor-demultiplexor, and a T1 rate Network modem.The Network modem connects to the NAWCAD Patuxent River "Blue Hose" Network. This network connects all the major facilities at NAWCAD. The RTPS has a similar set of equipment to connect that facility to the network.

The RS-422 SDLC data enters MFS over a set of Fiber Optic cables. The optical data are converted by Optelecom interface equipment to RS-422 electrical signals. The RS-422 signals connect to the MFS/RTPS link processor using a Digital Equipment Corporation (DEC) DSV11 SDLC wide area network interface card. This card and its associated driver allow standard DEC VMS operating system Input/Output (I/O) calls to be made by the interface processor software. The purpose of the interface processor software is to convert the data sent by the RTPS from Encore SEL floating point format to DEC VAX floating point format and place it into the proper MFS multiport shared memory simulation area. It also takes the appropriate data from the simulation shared data area and sends it to RTPS over the SDLC

link. The rate and number of variables passed is limited by the 256,000 bits/sec rate of the SDLC communications. Currently 100 32 bit variables are passed in each direction at 10 Hz. This rate and number of variables were selected to support the requirements of the first user of the link. Higher rates up to 30 samples per sec are possible with the current link configuration. Synchronization of the link is accomplished using a simple command/response method. The RTPS sends its data and in response the MFS VAX interface processor sends its data back to RTPS. The data are synchronized with a 0.1 sec time delay before simultaneous display at the Project Engineering Station.

The remainder of Figure 3 shows the distribution of the link data to the various parts of the simulation utilizing the MFS multiport memory. The multiport memory acts to tightly couple the processors that constitute the simulation into a multi-processor simulation computer system. The simulation cockpit can be moved to and interfaced with any of the MFS cockpit stations: the 40 foot DOME, the six degree of freedom Motion Base, either of the two lower fidelity display systems within the MFS computer room, or the high resolution CAE Helmet Mounted Display system.

RTPS Telemetry Link Configuration

The physical link consists of interface cards on the computers at each facility and encryption devices along with modems to send the data via the "blue hose".

Each RTPS stream (6 in all) consists of three Gould computers. A Data Channel Processor (DCP) , a Display Host Processor (DHP) and an Applications Processor (APP). The APP is the processor that hosts the software that implements the link. This machine is the Gould 3297. The current capability is to send 100 parameters in each direction simultaneously at 10 samples per sec. The data rate can easily be increased when a more powerful processor is implemented on the MFS end of the link. The software consists of a Flight Conditions Program (FCP) that collects telemetered samples from the telemetry front end and converts the data to VAX floating point format and sends a buffer of 100 samples plus time through the link to the MFS. There is an additional "task" that will read the port from the MFS. This task will read the 100 sample buffer and place the simulation data in the Current Value Table (CVT) at RTPS in the same manner as real aircraft calculated data. These samples have already been converted to Gould Floating Point format at the other end of the link prior to transmission.

Data flow is as follows: Aircraft data are collected on board the aircraft and telemetered to RTPS where it is decomutated and converted to engineering units in the Aydin System 2000. Engineering units data are then transferred to a shared memory area called the Current Value Table (CVT) where it is accessible by all processors. The APP hosts the software which collects a pre-selected subset of 100 parameters, converts the parameters to VAX floating point format, and passes them to a Gould T1L1 board which converts the data to a Synchronous Data Link Card (SDLC) format at 256 kb/sec. This data stream is passed through data encryption equipment to the base wide data communications system (Blue Hose) to the MFS where it is decrypted. At this point the data may be used to send aircraft control and other inputs to a simulation software package. The outputs from this package may then be buffered and sent back through the same path (it is a full duplex system) to the RTPS. An additional software package running on the APP will read this data from the MFS and output it to the CVT as if it were any other sample of calculated data. At this point any data in the CVT may be output to any display device in the Project Engineering Station (PES). This provides a capability to simultaneously display aircraft and simulation data for direct comparison. If strip charts are used as display devices, any of the 80 pens can be selected to display either aircraft data, locally calculated data or simulator output data. CRT plots may be chosen and selected measurements or critical aircraft data and simulator data may be viewed for potential to exceed engine or aircraft pre-established limits.

LINK APPLICATION

The link has the potential for numerous applications, one of which is real time support of flight test to provide additional safety of flight information which would otherwise be unavailable from telemetry alone. The project chosen to demonstrate this application was an F/A-18C asymmetric stores flying qualities program, completed in April 1995. The objective of this program was to expand the flight envelope and determine pilot flight restrictions with extremely large lateral weight asymmetry. A critical requirement was to prevent departure from controlled flight. Prevention of departure was mandatory because of the potential for structural damage to pylons/wing or entry into a spin from which recovery would be very difficult or not possible. The F/A-18C simulation hosted at the MFS was modified to provide critical departure prevention parameters from the simulation to be displayed to the flight test conductor.

SIMULATION PROGRAM DESCRIPTION

General

For this particular application the link was configured to have the ground based F/A-18C simulation "ride along" with the real airplane. The simulation was modified such that instantaneous maximum rolling surface available deflections and corresponding rolling moment available from rolling surface versus the moment required to maintain roll control were calculated and displayed to the test conductor at RTPS in real time. If either of these parameters exceeded 75% of maximum available the test maneuver was terminated immediately to prevent departure from controlled flight. This was a unique application of simulation data because of the complex digital flight control laws which continually changed the maximum control surface deflections available as a function of flight conditions such as Mach number, angle of attack, normal acceleration, altitude and airspeed.

F/A-18C Simulation Modifications

The generic aircraft simulation architecture used at the MFS was modified by adding a routine that sends and receives data through global memory to the link I/O software hosted at the MFS. Two buffers are stored in this global memory, one for receiving RTPS data and the other for sending simulation data to the RTPS stream. The simulation user can interactively specify what variables are located in each of these buffer slots in the MFS memory (although the locations are hard-coded on the RTPS side), and may apply a bias and scale factor to each variable. By default (i.e., simulation rides along with real airplane) the input variables from RTPS over-write the variable values used in the simulation, such that the simulated aircraft is always at the same flight condition and configuration as the test aircraft. The output variables to RTPS are typically calculated parameters that are unavailable to the RTPS stream, such as engine forces or aerodynamic coefficients, although any simulation variable may be sent to RTPS. This can be an efficient and non-impactive way of enhancing the data available to the flight test team. The aircraft simulations hosted at MFS have already been developed, so there is no need to add and verify special calculations to the flight conditions program hosted at RTPS for each flight test program.

The F-18 simulation hosted under this generic simulation architecture was modified to support the asymmetric stores loading flight test program. Two modules were added to provide two important pieces of information that are not normally available to the RTPS engineer test stations (ETS): maximum available surface deflections and maximum available roll power at a given flight condition. In order to enhance the effectiveness of this information, both were scaled from 0 to 1 for graphic display at the ETS. The following section describes the mechanization of the calculations for the parameters. An F/A-18C carrying a heavy external store on one wing only is illustrated in Figure 4.

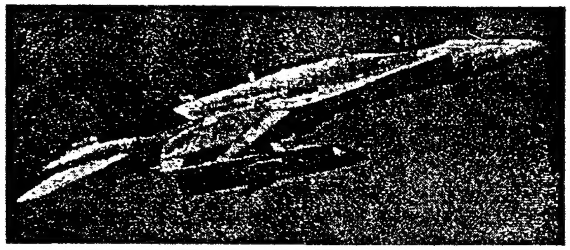

Figure 4. F/A-18C - Single GBU-24B/B External Store Loading

F/A-18C Available Vs Used Rolling Surface Control Deflection

The MFS was asked to provide the maximum differential surface deflections available at a given flight condition so that the flight test engineers would be able to determine a "knock-it-off" point when the rolling surfaces neared saturation limits. The Project Engineer Station (PES) real time graphic display is driven by the summation of the current (i.e., actual aircraft surface positions divided by the summation of the maximum theoretical positions corresponding to full lateral stick , equation (1). The maximum theoretical positions are calculated by sending full left and right stick to a modified version of the F/A-18C lateral axis control system. The FORTRAN control laws were modified to remove dynamic filters so that rapidly changing maximum control surface limits could be determined immediately. Using this mechanization there was no delay in calculating and displaying maximum rolling surface deflection data to the test conductor. In equation (1), all entries are total differential deflections, not deltas to the average deflection. The % Rolling_Surface$_{used}$ parameter is calculated for both full left and right lateral stick deflection. The output parameter to RTPS is the ratio of current and maximum available left and right rolling surface deflection.

$$\%Rolling\_Surface_{used} = \frac{\delta_{aileron} + \delta_{diff\_stab} + \delta_{diff\_lef} + \delta_{tef}}{\delta_{\max\_aileron} + \delta_{\max\_diff\_stab} + \delta_{\max\_diff\_lef} + \delta_{\max\_diff\_tef}} \times 100 \qquad (1)$$

where, δ corresponds to respective current or maximum roll control surface deflections.

The numerator and denominator of equation (1) represent the current and maximum available rolling surface deflections respectively.

F/A-18C Available Vs Used Rolling Moment

The maximum roll power available is calculated by sending the maximum surface deflections from the maximum rolling surface available calculations to a modified section of the aerodynamic model, which calculates the roll moment coefficient based on these deflections. The lateral asymmetry is calculated at RTPS and sent to the F/A-18C simulation as the rolling moment caused by the asymmetric loading at 1G. This asymmetry is multiplied by the filtered signal from the real airplane normal accelerometer. The resulting product represents the roll power that the rolling surfaces must generate to maintain roll control. The effective asymmetric roll moment shown in equation (2) is divided by the maximum roll moment available to both the left and right:

$$\%Roll\_Moment_{used} = \frac{Roll\_Moment_{asymmetry} \times Load\_Factor}{Roll\_Moment_{\max\_avail}} \times 100 \qquad (2)$$

The numerator and denominator of equation (2) represent the current and maximum available rolling moments respectively. The ratio is an estimate of the percentage of roll power (i.e., rolling moment) used to control the asymmetric load; it implicitly shows how much roll power remains for maneuvering.

Real Time Departure Prevention Display

A real time display, Figure 5 was developed which utilized the F/A-18C simulation derived rolling surface and rolling moment calculations to present immediate information to the test conductor on how close the airplane was to potential departure from controlled flight.

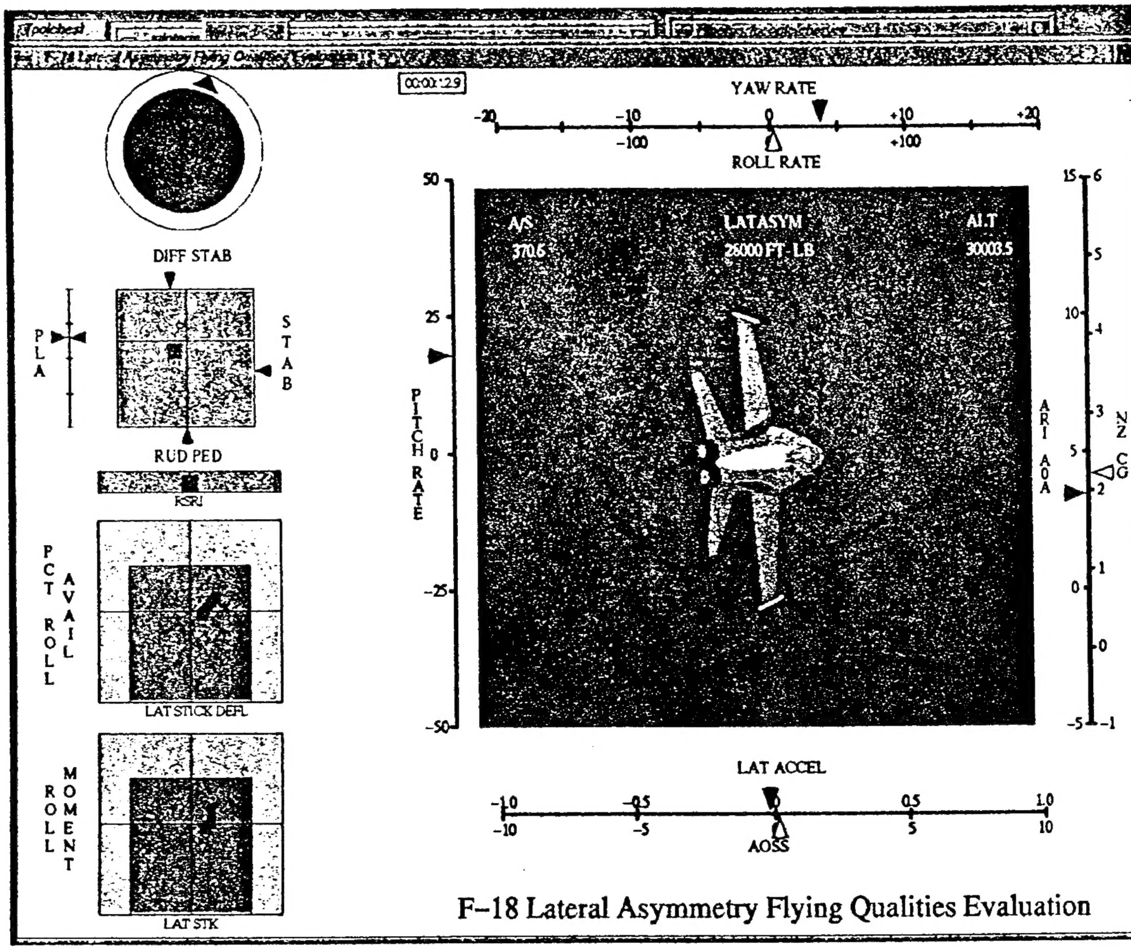

Figure 5. Real Time Departure Prevention Display

This display was the first of its kind at NAWCAD to merge simulation and aircraft data to be used to reduce the risk of departure from controlled flight in a real time environment.

Potential New Applications

The MFS-RTPS link at NAWCAD is a new capability derived from existing capabilities looking for new and unique applications. The link can be configured in various ways for particular applications. In the near future NAWCAD Patuxent River may use the link to support training of the complete aircrew on tactical aircraft such as the F/A-18E/F. The Aviation Safety Office has recognized the need to focus on aircrew training for tactical jet aircraft to prepare for flight test mission scenarios. The expanded aircrew will include the test pilots flying a tactical aircraft simulation at MFS using the Patuxent River visual data base, the aircraft ground controllers at the Chesapeake Test Range (aircraft tracking facility) and the test conductors and engineers at RTPS. Video cameras will be set up at MFS to record pilot actions/reactions to various mission scenarios which will include communications failures (e.g., loss of telemetry), lose of radar coverage, simulated control system failure, simulated engine failures etc.

Other potential applications of the link include quick-look real time assessments of simulation fidelity by the calculation and comparison of actual and simulation predicted force and moment data for the aircraft under test. In this scenario the simulation is "driven" by the same control surface inputs as the real airplane under test. The force and moment coefficient information could be displayed in real time or post flight for determination of places within the flight envelope where the simulation exhibited good or poor fidelity. This has the potential to reduce the time it takes to update simulations to pace flight testing.

For highly complex digital flight control systems not all of the flight control law signals are monitored by the aircraft multiplex bus. The ability of the simulation to provide all of the signals has the potential to significantly increase test engineer understanding of how the flight control laws are interacting with aircraft dynamics in real time. This concept is easily extended to various aircraft subsystems models which include propulsion system models, avionics models, INS models, air data system models etc. In the near future NAWCAD will have significantly increased high performance computer capabilities which are expected to significantly increase the ability to model complex systems including radar systems with high fidelity in real time.

CONCLUSIONS

The linking of high fidelity simulation models with real aircraft parameters in real time to enhance flight safety has been successfully demonstrated. Numerous applications have yet to be developed. As the cost of flight testing highly complex systems increases the use of real time simulation support to reduce overall cost and enhance flight safety from a crew resource management and training perspective will increase. Crew resource training in the past has focused on aircrew only. In the new testing environment high fidelity simulation links and high performance computers will expand this concept to include the entire test team. The ability to link simulation and actual aircraft data in real time has the potential to significantly improve our ability to test and evaluate complex aircraft systems in a real time environment.

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SYMBOLS & ABBREVIATIONS

$\delta_{aileron} = Differential\_aileron$

$\delta_{diff\_stab} = Differential\_stabilator$

$\delta_{diff\_tef} = Differential\_trailing\_edge\_flap$

$\delta_{diff\_lef} = Differential\_leading\_edge\_flap$